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DYNAMIC STRAIN TOLERANCE
OF BLOOD VESSELS AT
DIFFERENT POSTMORTEM CONDITIONS

C. G. P. Löwenhielm

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Peter Löwenhielm

Department of Forensic Medicine

University of Lund

Lund, Sweden

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Summary

Parasagittal bridging veins from cows, carotid arteries from rats and external jugular veins from rats have been tested with regard to the ultimate strain. The tests were performed just after death and two days after death. The bridging veins from cows were kept in a wet chamber, while the blood vessels from rats were kept either in situ or in a wet chamber. Strain rates ranging from 5/sec. to 2500/sec. were used. The results indicate that at higher strain rates, the ultimate strain for bridging veins from cows is lower just after death than two days after death. Regarding the blood vessels from rats (tested at high strain rates) no significant difference from results from tests just after death was obtained after two days if the blood vessels had been kept in situ while a significant increase in ultimate strain was observed if the blood vessels had been kept in a wet chamber.

Introduction

In biomechanical research concerning mechanical properties and trauma tolerance levels of human tissues, whole cadavers and cadaver specimens have frequently been used. In these cases it is of crucial importance to consider to which extent a specific tissue or organ maintains in vivo mechanical properties. After death decomposition of tissues begins. Environmental factors such as temperature, humidity, microbiological agents, etc., contribute to the rate of auto-lysis. It is not known how long after death in vivo mechanical properties can be assumed.

Disruption of parasagittal bridging veins (vv. cerebri sup.) is a common finding in head trauma cases, especially in traffic casualties. Investigations of the mechanical properties of cadaver bridging veins (Löwenhielm, 1974a) and tolerance levels concerning disruption of cadaver bridging veins (Löwenhielm, 1974b) have been performed. The aim of the present study is to validate these investigations by a study of post mortem changes of mechanical properties in animal blood vessels. For this purpose tensile tests have been performed on the carotid artery and the external jugular vein of white rats and on the parasagittal bridging veins of cows. The tests were carried out just after death and two days post mortem.

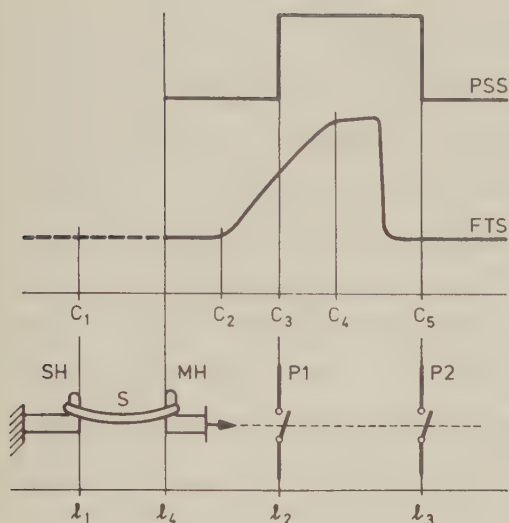
Materials and Methods

Blood vessels from rats and cows were tested with regard to the ultimate strain in longitudinal tension at various strain rates, such that each test was performed at a constant strain rate. The test device is pneumatically operated. The general idea was to give one end of the bridging vein a constant velocity while the other end is kept stationary. This is achieved by using speed regulated pneumatic pistons and as described by Löwenhielm (1974a). The driving end of the test device used can be given an instant velocity ranging between 0.015 and 15 m/sec., approximately. The test specimen is tied to two hooks, one of which is connected to the driving end and the other to a stationary piezoelectric force transducer. The force-time history is recorded by means of a transient recorder. The driving end interacts with two position switches mounted at a well defined distance apart, (cf. fig. 1). The average velocity is then given by the time lag between the signals from the switches. Reduction of velocity, primarily due to friction is less than 4 per cent and the velocity is therefore considered constant. At high velocities disturbing vibration occurred in the test equipment. The minimum sample interval of the transient recorder is 0.01 msec. The signal was low-pass filtered by using a 2-pole Butterworth active filter with a cut-off frequency of 5000 Hz and a damping of 6 dB/octave in order to avoid aliasing. Remaining noise was filtered numerically. For the electronical set-up, cf. fig. 2.

Referring to fig. 1 the ultimate strain can be written:

$$\epsilon = \frac{C_4 - C_2}{C_2 - C_1}$$

where C_1 is defined as the cell number of the transient recorder corresponding to the stationary hook. C_2 corresponds to completely stretched blood vessels



- PSS Signal from the position switches
 FTS Force transducer signal
 SH Stationary hook
 MH Moving hook
 S Test specimen
 P1, P2 Position switches
 C_i Transient recorder cell number
 l_i Coordinates in the testdevice

Fig. 1

Triggering, velocity and signal recording.

at negligible load. From fig. 1 it is evident that

$$C_1 = C_3 - \frac{l_2 - l_1}{l_3 - l_2} \cdot (C_5 - C_3)$$

The strain rate is defined as

$$\dot{\epsilon} = \frac{\text{impact velocity}}{\text{original length}} = \frac{1}{(C_2 - C_1) \cdot S}$$

where S is the sample interval of the transient recorder.

The carotid artery and the jugular vein from approximately three months old rats were tested just after death or two days post mortem. The rats were anesthetized with pentobarbital intraperitoneally and the blood vessels were isolated and tested at once. Concerning the tests performed after two days, the blood vessels were preserved in two different ways. Some blood vessels were left in situ in the sacrificed animal and removed just before testing. Others, removed at once, were kept at 18°C in a wet chamber: Filter papers soaked in physiological saline solution contained in a closed Petri dish. In all 36 carotid arteries were successfully tested, 15 just after death and 21 after two days (13 in situ and 8 in wet chamber). Twentysix jugular veins were tested, 8 just after death and 18 after two days (7 in situ and 11 in wet chamber).

To obtain bridging veins big enough to be easy to handle and test, cows were chosen as test animals. Specimens were obtained from cows (about two years old) of the SLB breed of Swedish livestock. At the time of slaughter about ten bridging veins were secured in one session. The specimens were kept in a wet chamber. About five of the bridging veins obtained at one session were tested as soon as possible. About one hour elapsed between the slaughter of the cows and the testing. The remaining vessels were kept in the wet chamber for about 2 days at a temperature of $+18^{\circ}\text{C}$. This treatment was intended to correspond to cadaver handling in the tests from which tolerance levels for bridging vein disruption were calculated (Löwenhielm, 1974b). Fourtyseven bridging veins were tested. 26 just after death and 21 after two days in a wet chamber.

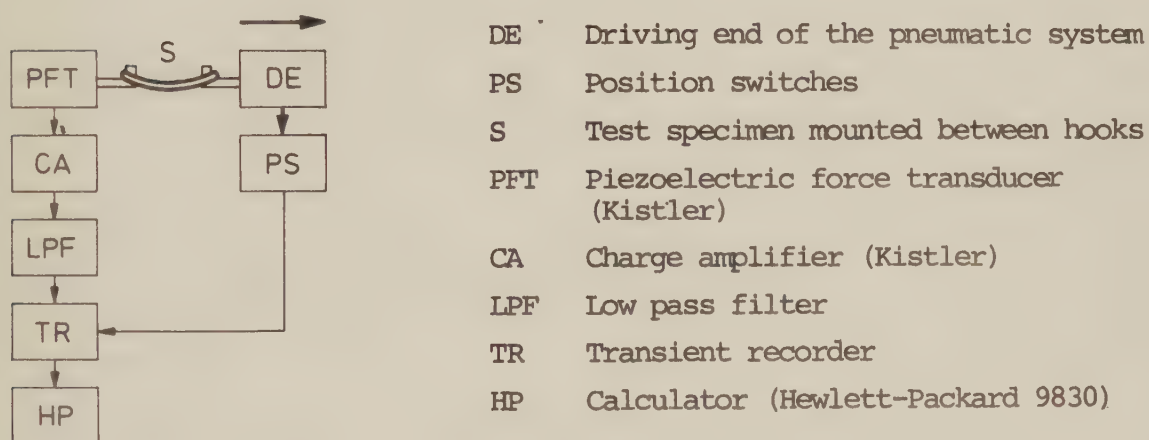


Fig. 2

Schematic sketch of the test equipment.

Results

In figs. 3 and 4 the ultimate strain versus strain rate for carotid arteries and jugular veins from rats and in fig. 5 for parasagittal bridging veins from cows is given. With regard to the different strain rates the results have been grouped in one low, one medium and one high group. The average ultimate strain for each group is presented in Table 1.

The jugular veins and carotid arteries from rats, which had been kept in situ and tested after two days, showed no difference in ultimate strain compared to the blood vessels tested just after death. However, if the blood vessels had been removed and kept in a wet chamber for two days, a significant increase in ultimate strain ($p < 0.1\%$) was obtained.

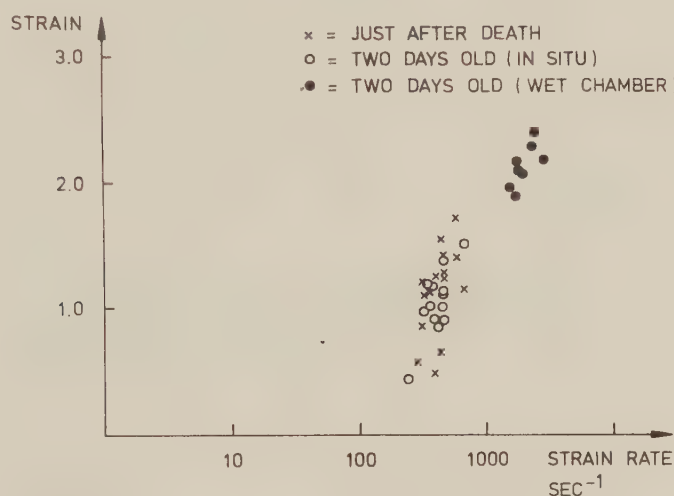


Fig. 3

Ultimate strain versus strain rate relationship for the carotid artery from rats.

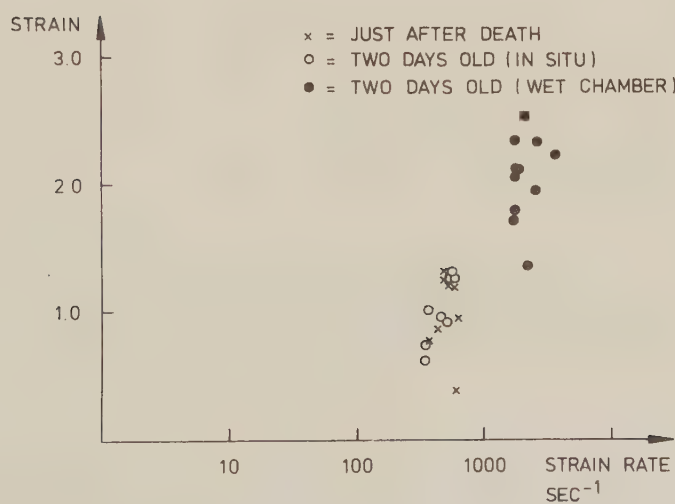


Fig. 4

Ultimate strain versus strain rate relationship for the external jugular vein from rats.

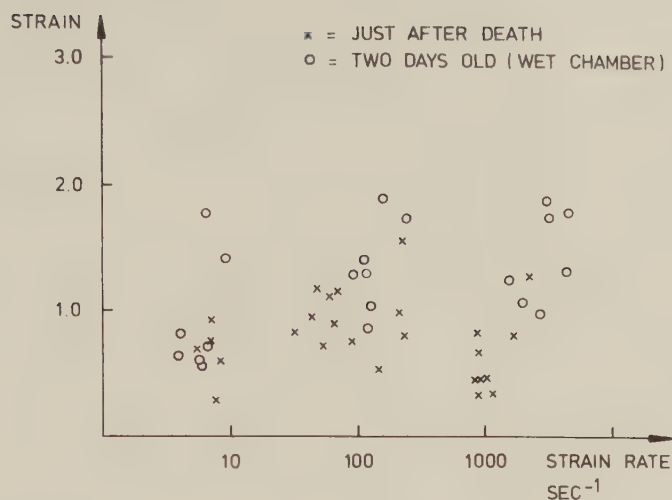


Fig. 5

Ultimate strain versus strain rate relationship for parasagittal bridging veins from cows.

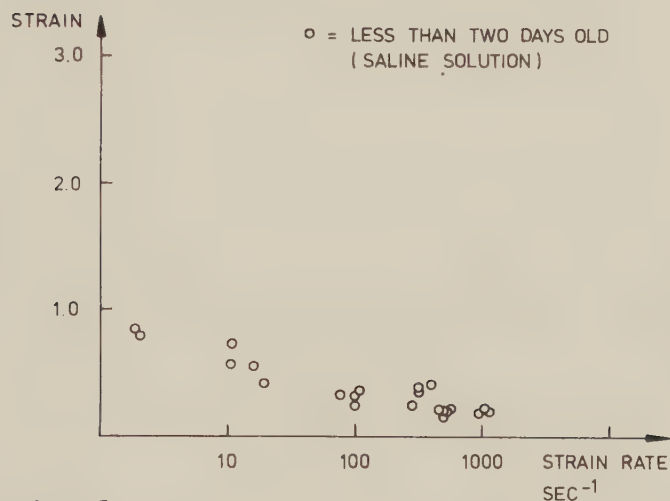


Fig. 6

Ultimate strain versus strain rate relationship for human parasagittal bridging veins (Löwenhielm, 1974a)

As regards the bridging veins from cows, differences in the ultimate strain properties were noticed if the tests were carried out just after death or after two days (wet chamber). The differences increased with increasing strain rate: In the low group no significant difference was obtained, while significant difference was obtained in the medium ($p < 5\%$) and the high ($p < 0.1\%$) strain rate group, the two days post mortem veins having a higher ultimate strain.

TABLE 1

Ultimate elongation of blood vessels from cows and rats tested just after death and two days post mortem

	Strain rate		
	10/sec.	100/sec.	1000/sec.
Bridging vein from cow tested:			
just after death	$0.63^{+0.24}$ S.D.	$0.93^{+0.27}$ S.D.	$0.60^{+0.30}$ S.D.
after two days (kept in wet chamber)	$0.91^{+0.47}$ S.D.	$1.33^{+0.36}$ S.D.	$1.41^{+0.37}$ S.D.
Carotid artery from rats tested:			
just after death			$1.11^{+0.37}$ S.D.
after two days (kept in situ)			$1.03^{+0.26}$ S.D.
after two days (kept in wet chamber)			$2.10^{+0.16}$ S.D.
Jugular vein from rats tested:			
just after death			$0.99^{+0.30}$ S.D.
after two days (kept in situ)			$0.99^{+0.25}$ S.D.
after two days (kept in wet chamber)			$2.01^{+0.33}$ S.D.

TABLE 2

Ultimate tensile force (in Newton) of bridging veins from cows tested just after death and two days post mortem

	Strain rate		
	10/sec.	100/sec.	1000/sec.
Test just after death	$0.37^{+0.17}$ S.D.	$0.41^{+0.17}$ S.D.	$0.52^{+0.36}$ S.D.
after two days (kept in wet chamber)	$0.25^{+0.12}$ S.D.	$0.43^{+0.21}$ S.D.	$0.62^{+0.15}$ S.D.

In fig. 6 the ultimate strain versus the strain rate for human bridging veins (Löwenhielm, 1974a) is reproduced for comparison. In Table 2 the average breaking force for bridging veins from cows is presented.

Discussion

Yamada (1970) refers to a mechanically stabilized state for biological tissue, during which the mechanical properties are not altered for a certain time post mortem. The mechanical properties during this state are not necessarily the same as those which would be obtained if the tests were performed in vivo or just after death. According to Yamada (1970) the ultimate elongation for blood vessels is lower just after death compared to the mechanically stabilized state. To achieve the mechanically stabilized state the tissue specimens were put in saline solution and soaked over night. Saturation with water and for skeletal muscle, also disappearance of rigor mortis is believed to be the causative mechanism in obtaining the mechanically stabilized state. The duration of the mechanically stabilized state varies for different tissues. According to Koishi (1951), the mechanically stabilized state for blood vessels is maintained for four days.

The present results confirm this view as regards the blood vessels that had been kept in a wet chamber. However, no increase in ultimate strain was obtained for the blood vessels that had been kept in situ after death. Preservation of the blood vessels in situ involves a different milieu from that of a wet chamber. It seems likely, that entrance to the mechanically stabilized state is hindered or delayed.

The ultimate strain is lower for human bridging veins (Löwenhielm, 1974a), especially at high strain rates, than for bridging veins from cows. This difference is not necessarily explained solely by differences between species but may perhaps to some extent be due to age differences. The cow bridging veins were taken from animals being about two years old at slaughter (about 1/6 of their life span) while the human bridging veins used in the tests by Löwenhielm (1974a) were taken from considerably older individuals. With time a firmer anchorage between the surface of the brain and the dura along the superior sagittal sinus is formed by proliferating connective tissue. The ultimate strain for firm connective tis-

sue at static loading is considerably lower than for blood vessels (Yamada, 1970) and it seems likely that the strain versus strain rate characteristic changes with age.

The present results indicate that the ultimate strain for bridging veins from cows and for jugular veins and carotid arteries from rats is increased if these blood vessels are kept in a wet chamber. It seems likely that human blood vessels should be affected in the same manner. The ultimate strain for human bridging veins (Löwenhielm, 1974a), was investigated on test specimens kept in physiological saline solution for less than two days. This fact suggests that the ultimate strain might be lower for fresh human bridging veins and that this reduction could be substantial for high rates of strain. The present results do not allow a quantitative estimation, though, and it must be remembered that the proliferating connective tissue may mask this effect.

Tolérance levels for bridging vein disruption have been evaluated from cadaver tests (Voigt and Lange, 1971; Löwenhielm, 1974b), with the bridging veins in situ. The ultimate strain obtained for rat blood vessels, which had been kept in situ, did not differ from those tested just after death. This fact indicates that the tolerance levels suggested for human bridging vein disruption were adequately obtained. Such a comparison involves some hazards though because of different species, different kinds of blood vessels, and different in situ milieu. Thus, it cannot be ruled out that the human bridging veins may be saturated by the intracranial fluid after death and thus enter the mechanically stabilized state. In order to investigate the conceivable significance of this possibility, an estimate of possible strain rates associated with bridging vein disruption in practical situations (such as car crashes) should be made. Thus, from Table 1 it is seen that the difference between tests after two days with cow bridging veins kept in wet chamber and tests just after death may not be significant for strain rates around 10 sec^{-1} , but is so for strain rates around 100 sec^{-1} and above. In practical situations gliding contusions, i.e. paramedially situated subcortical streaklike bleedings of venous origin (Voigt et.al., 1977), often seem to occur at strain rates below 100 sec^{-1} (Löwenhielm, 1975). Now it is known that disruption of parasagittal bridging veins often occurs together with gliding contusions (Voigt et.al., 1977). Thus, the interesting

strain rates should be lower than about 100 sec^{-1} , say strain rates between 10 and 100 sec^{-1} . Therefore, the bridging veins in the cadaver tests by Voigt and Lange, (1971), in which strain rates of about 40 sec^{-1} were involved might stand a larger elongation after two days in situ than in vivo and consequently a reduction of the tolerance levels calculated by Löwenhielm (1974b) might be justified. Such a reduction, however, does not need to be very large since the strain rates are not very high. Moreover, it should affect only the critical level for angular acceleration, since the latter level will be decisive only for low strain rates. (It should be observed that the criterion for bridging vein disruption implies that both a critical angular acceleration and a critical angular velocity change shall be exceeded). A reduction of the previously suggested critical level for head angular velocity change is also indicated by a recent case study (Löwenhielm, 1977).

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